Project Title:

Feasibility Study of the Application of Unmanned Aerial Vehicles Transportation Applications

Research Agency: University of Florida
ARCH Building, University of Florida, Gainesville, FL 32611-5706

Project Director: Dr. Zhong Ren Peng

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Estimated Cost: $75,000

Estimated Time: 1 year

Introduction

Unmanned Aerial Vehicles (UAVs) or Unmanned Aerial Systems (UASs), known for their easy maneuvering, great flexibility and low costs, are promised to be a great aerial sensor for transportation applications. UAVs can be launched and deployed within minutes, and send data back in real time. They can provide bird's eye view over an intersection or a large area, and provide continuous observation of traffic flow formation and dissipation. Therefore, as an aerial traffic information gathering platform, they have been becoming more prominent in transportation planning, engineering and operation. It could be an effective airborne surveillance system for rapid deployment with low costs. As the State of Georgia strives for the establishment of one of the six UAV test sites, this is a great opportunity for the Department of Transportation to explore the benefits, capabilities as well as problems of UAVs for the operations of each division within the Department.

However, there are also dangers and pitfalls of using UAV in civilian transportation applications. For example, there are potential risks of clashes, low image/video quality due to wind and/or selections of different UAV technologies and sensor types as will be discussed later in this proposal. These dangers and pitfalls may not be fully reflected in the literature and could not be fully realized withouth personal flying experience. As such, UAV cannot be used for all transportation applications, and not all UAV applications are as cost-effective as the tradition methods.

Therefore, it is very important to have a full understanding of the pros and cons of the UAV technologies, the applicability and the cost-effectiveness of UAVs in different transportation applications. This feasibility study will analyze how UAV can be used to enhance the operations and functions of each Division within the Department, and to determine the costs and benefits, opportunities and barriers, as well as the feasibility of utilizing UAVs in different applications.

Objectives

The ultimate goal of this study is to provide the Department with specific suggestions about the most effective applications of UAV in enhancing the Department's operations and functions, as well as the most proper UAV technologies in transportation applications. Specifically, the objectives of this study are:

1. Provide an assessment framework to assess the applicability and cost-effectiveness of UAV and sensing technologies in different transportation applications. Assess the feasibility, as well as the pros and cons of different UAV technologies in transportation applications, such as types (fixed-wing UAV and rotary UAV), power sources (electrical UAV or fuel-powered UAV), the size, maneuverability, range, endurance, payload capacity, equipment needs, wind resistance, and cost benefits of the applications.

2. Suggesting the potential and most cost-effective applications of UAV across all GDOT divisions by interviewing division staff, literature review, cost-benefit analysis, and based on the research team's previous experiments and experience in using UAVs.

Existing Work

Tue to the restriction of the Federal Aviation Administration (FAA), the research of UAV applications in transportation is limited. Most studies focus on traffic data collections, including static remote sensing images and real time traffic information, as well as non-motorized travel data. The state of Washington has studied the capabilities of UAVs as an avalanche surveillance tool (McCormack, 2008), and the Florida Department of Transportation has studied the feasibility of using surveillance video from UAVs for traffic control and incident management (Latchman, 2005). Other studies explored the use of UAV for traffic surveillance and monitoring (Dong, 2007; UDOT, 2009).

As early as the year 2000, the research project WITAS was started which focused on the UAVs flight control system on the first stage (Doherty, 2000). Srinivasan and Latchman (2004) introduced ATSS (Airborne Traffic Surveillance System), a project funded by the Florida Department of Transportation, attempting to make this vision a reality. They proposed an approach for transmission of data and multimedia video streams over FDOT's microwave IP networks. Carroll and Rathbone *(2002*) demonstrated the feasibility of using a small-unmanned airborne data acquisition system (ADAS) for traffic surveillance. According to their study, the ADAS can play a cost-saving role in about half of all data collection procedures and can reduce the total cost by 20 percent. There are also studies on UAVs route planning. Peng (2011, 2012) proposed route optimization algorithms for UAVs route planning on sparse road network. Lee and Huang *(2003*) studied the strategies of path-planning for a UAV to track a ground vehicle.

Several studies focus on traffic information extraction from processing UAV video. Coifman and Mccord *(2004 and 2006*) demonstrated several applications by using data from a UAV flying in an urban environment: determining level of service (LOS), estimating average annual daily travel (AADT), documenting intersection operations and measuring origin destination flow. Hickman and his team (2006 and 2010) developed video image sequence software named TRAVIS (Tracking and Registration of Airborne Video Image Sequence) based on videos collected from manned airplane. Puri and Valavanis (2007) used UAVs to collect real-time spatial-temporal visual data to generate traffic-related statistical profiles, serving as inputs to traffic simulation models. Angel and Hickman (2002) outline methods to generate estimates of speeds, travel times, densities, and queuing delays from UAV video. Similar research has also been conducted by Heintz (2007) and Reinartz (2006). These researches show that UAVs is a promising traffic data collection tool.

In the recent years more and more new applications of UAV in transportation are studied and the government also starts the feasibility study of the deployment of this new device for transportation. Steven Barfuss et al. (2012) took advantage of high-resolution aerial photography obtained from UAV to aid Utah Department of Transportation (UDOT) in monitoring and documenting State Roadway structures and associated issues. Egziabher et al. (2011 and 2008) developed a framework for the design of concept of operations (CONOP), which use UAV to support intelligent transportation system (ITS) applications and transportation infrastructure monitoring. The similar project funded by USDOT is carried out by Hart and Gharaibeh (2010). Zhang (2006) developed efficient methods and systems to process UAV images and identify and

quantify road condition parameters such as rutting, potholes, and road surface roughness. Based on Zhang's job, Rouss and Brooks (2012) continuing their research on unpaved road surface detection with UAV. The state of Washington, Florida Department of Transportation and UDOT have carried out preliminary feasibility study of the deployment of the UAV in transportation (McCormack, 2008; Latchman, 2005; UDOT, 2009). But there is no study on the quantitative Cost-benefit analysis of the UAV deployment of multiple divisions of transportation department.

For the PI's own work, we have carried out many experiments using the MD4-1000 UAV (see Figure 5a and http://www.microdrones.com/products/md4-1000/md4-1000-key-information.php) to develop efficient flight routing algorithms for transportation networks, study intersection traffic conflicts and queues, collect traffic flow information on arterial road, work zone traffic observation and flow analysis, integration of UAV data and traffic data from loop detectors and floating cars, the use of UAV for emergency response. We are also working on the use of ambient gas sensor (CO sensor and PM sensor) under the UAV to collect air quality data to map the spatial-temporal distribution of air pollution and model its relationship with transportation and land use.

For example, Figs. 1-4 are UAV experiments carried out by PI's research group in USA and China on expressways and urban roads. Based on the video image processing program we developed, we found that the accuracy and precision of the traffic information detected from UAV depends on the UAV type, flight speed, flight altitude, wind, sensors and etc. According to experiment results by our research team, the rotary wing UAV is more appropriate for collect traffic information at places such as intersection and interchanges, and fixed wing UAV shows better performance for traffic incident management and collect traffic flow data between two points. We also found that UAV flight altitude is also an important parameter for traffic information detection. Based on our experiment results, the detection rate of traffic flow is above 90% and the detection of the vehicle speed is 87% when the flight height is 80 meter (Fig. 5).

Fig. 1 UAV experiments in Xinjian Expressway in China (2012)

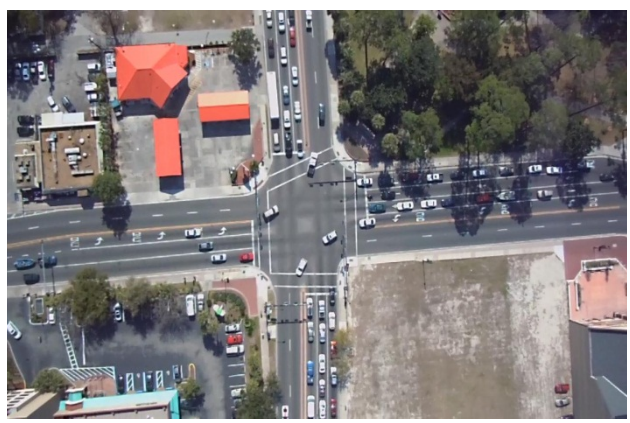

Fig. 2 UAV experiment on an intersection in Gainesville, USA (Aug. 2011)

Fig. 3 Long traffic queue detection using UAV in Shanghai, China (June. 2012)

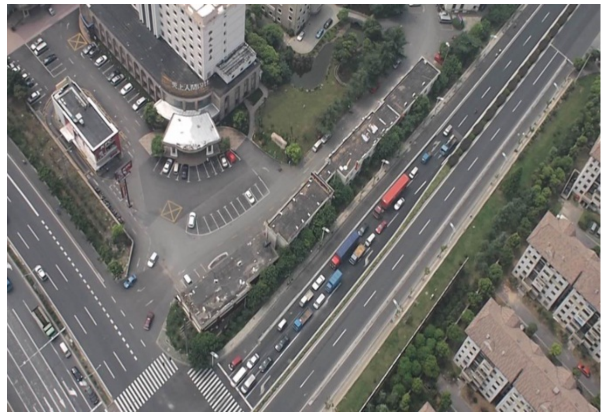

Fig. 4 Traffic flow detection using UAV in Shanghai, China (July. 2012)

a. UAV used in the experiment b. vehicle automatic detection

Fig 5 Vehicle speed detection on expressway

As it can be seen from these studies, UAV has the potential to become an important aerial sensor for traffic data collection and air quality data collection. The real value, however, lies on the integration of aerial data with ground-based traffic sensor data. These potentials will be realized as the US Congress and FAA develops policy and certification requirements for UAV integration into the National Airspace System (NAS) in 2015.

Work Plan

Task 1. Establish An Assessment Framework of UAV Applications in Transportation

Different transportation applications have different requirement to different UAV technologies, including UAV size, type, maneuverability, range, endurance, payload capacity, equipment needs, wind resistance, and have different cost-effectiveness. Thus

an assessment framework needs to be established as shown in Table 1.

Table 1 An Assessment Framework of UAV Applications In Transportation									
Applications	UAV Type	Payload	Flight Speed	Endurance	Power Sources	Flight Altitude	Wind Resistance	Sensors	Cost-Effectiveness
Road pavement monitoring									
road planning and design									
Traffic information acquisition									
Intersection traffic conflict and queue length observation									
Accident black spot observation									
Parking condition observation									
Corridor traffic flow information gathering									
Vehicle following									
Lane change behavior observation									
Ramp traffic observation									
Construction zone traffic behavior surveillance									
Driving violation detection									
Non-motorized traffic information observation									

Bridge Condition assessment									
Air quality 4-D mapping and analysis									

UAV Types: There are different ways to classify the UAV systems, based on size, control system, range, takeoff and landing, and so on. But for civilian UAV system, it is basically divided into two types, the rotary wing UAV and the fixed wing UAV. The rotary wing UAV is a VTOL-aircraft (Vertical Take Off and Landing) that can hover over any target, and can take off and land without any runway. The fixed wing UAV cannot hover and need a runway or a launcher to launch, but it typically has more endurance than a rotary wind UAV.

Payload: depending on the UAV, the payload on civilian UAVs is typically in the range of 0.5 – 15 kg. This has important implications on the type of sensors and other accessories that the UAV can carry.

Flight Speed: The rotary wing typically has slower speed than the fixed wind speed. In most cases, this has little impacts, such as if you want to use UAV to collect road and traffic information. But, if you want to use the UAV to chase individual vehicles on freeways, you need to use the fixed wind UAV with higher speed.

Endurance: The civilian UAV varies greatly in endurance, ranging from 15 minutes to 12 hours.

Power Source: Currently, there are two power sources for civilian UAV: fuel-based and battery-based, which has important implications of endurance and risks. Fuel-based UAV has long endurance but is less safe while the battery-based UAV has shorter endurance but is safer.

Flight Altitude: Civilian UAV has large variations in terms of flight altitude. The maximal flight altitude of most civilian UAVs ranges from 300 – 1000 meters. For applications that need a large bird’s-eye view of the transportation network, a UAV with a high altitude would be required.

Wind Resistance: Civilian UAV, especially those with small size, typically cannot resist strong wind (e.g., large than 7m/s). But it varies depending on the UAV. This has very important implications for the risk factors, the quality of images and videos collected, and the image processing programs.

Sensors: Different applications require different sensors, such as spectral cameras with different bands, LiDAR, and gas sensors (for measuring air quality). Some UAVs are equipped with easy integrations with different sensors while others don’t. The selection of sensors depends largely on the UAV and its payload, as well as the transportation

applications.

Cost-effectiveness: UAV may not fit all transportation applications, and not all applications require a UAV. This study will evaluate the cost-effectiveness of UAV in different applications from the perspective of comparing the costs and benefits of using UAV with those of using existing methods, on an application by application base.

This assessment framework will be developed together with staff in different divisions of GDOT, from the literature and PI's personal UAV experiment experience, plus the PI's extensive network of UAV professionals. Meetings with GDOT staff will be conducted to determine the desired transportation applications using UAV. Surveys and interviews will be conducted to assess the applicability and requirements of each UAV technology for different transportation applications. A ranking system will be developed of the applicability and cost-effectiveness of the UAV technologies for different transportation applications based on application needs.

Deliverable:

A complete assessment framework for UAV applications in Transportation.

Task 2. Detailed Analysis of UAV Applications in Transportation

After reviewing existing study and ongoing research, a brief review of each GDOT Division's operation and mission will be performed with an in-depth analysis of those divisions and offices that have the potential to benefit from UAVs.

User requirements will be established for each identified transportation applications. In order to meet these requirements, UAV technology and sensor requirements will be developed, considering, but not limited to primary and secondary mission definitions, UAV size, maneuverability, range, endurance, payload capacity and equipment needs.

Once the requirements and ultimate utility are fully determined, an estimated cost will be developed for UAV and sensor purchase, maintenance, and operation. This cost will be evaluated against the potential for performance enhancement and cost savings to the GDOT by comparing it with traditional methods and will be developed into a cost effective analysis report.

A detailed review of the applicability and cost-effectiveness of UAV technologies will be conducted for each application based on the assessment framework as shown in Table 1. Here are some examples. More applications will be added based on the discussions with staff in divisions in GDOT.

1 Traffic information acquisition

Traditional traffic information acquisition is through point sensors. Data collected reflect traffic information at each point, and there is continuous traffic flow data in between the points.

Also, the traditional traffic sensor can detect the existing of queues, but could not detect the length of the queues except CCTVs at some points. Compared with using conventional detectors to collect traffic data, using UAV has several advantages. First, UAV, hovering over specific areas, can focus on data collection from a specific link or intersection, can cruise repeatedly over a road segment and can fly in a very low altitude. Second, UAV can hover right over any interchanges or intersections to detect the formation and dissipation process of traffic congestions, queuing, and turning behaviors, etc. UAV offer a very reliable way of collecting spatial-temporal data.

In this study, we will summarize the pros and cons of rotary wing and fixed wing UAV in collecting traffic information at particularly points, road segments and an area with multiple intersections/interchanges and road segments based on our experiments and from the literature. This includes the precision of UAV data collection in acquiring traffic flow data, volume, density and speed, traffic conflicts, queuing formation and dissipation; the requirement of flight height, speed and endurance. We will also conduct a cost-effective analysis by comparing with traditional data connection methods such as loop detector and CCTV for the same information collected.

2. Detection of driving violation actions on urban arterial and freeway

UAV, different from the fixed-location cameras, could follow dynamic traffic flows and vehicles, so that traffic conditions and violation could be monitored regularly without preset location or route limitations. The information could be sent to vehicles of the law enforcement personnel and/or control center in real time. This study will review the communication issues and image transmission issues between the UAV and vehicles on the road, as well as other issues.

3. Driving behavior analysis under congestion and saturation situations

UAV is particularly useful for observing driving behavior such as lane change and car following and illegal movement. This study will investigate the required UAV technologies and operation requirement to better study the driving behavior. This is useful for GDOT to provide insights for traffic management, and to provide data to feed into and validate traffic flow simulation models, and to study the boundary situations, determine the spatial and temporal distribution of the probability and impacts of oversaturation.

4. Work zone traffic surveillance

UAV is a very flexible traffic surveillance tool for observing traffic behavior and collecting traffic information at work zones. This study will study the feasibility and requirements of using UAV for work zone traffic information collection and management.

5. Road pavement and unpaved road condition monitoring

UAV, with its low altitude and flexible flying routes, can provide a very good tool to monitor road conditions, particularly unpaved road conditions. According to the Federal Highway Administration (FHWA), in 2008 there were 1,324,245 miles of unpaved road in the United

States, accounting for almost 33% of the over 4 million miles of road in our national transportation infrastructure (FHWA and USDOT 2010). Local governments and transportation agencies are responsible for a large part of this unpaved infrastructure. These agencies need to be able to assess cost-effectively the condition of the infrastructure on a periodic basis in order to manage effectively these roads, and to optimize for resource allocation. Paved and unpaved road condition can be easily assessed visually; the texture, color, shapes, surface imperfections, and other characteristics allow us to identify and classify various problems with the road. With proper software and sensor (such as mini-LiDAR), the assessment of road conditions could be more precise. This study will evaluate the UAV requirements, sensor requirements and flight altitude and speed requirement, as well as costs-effectiveness of using UAV for road condition monitoring.

6. Bridge condition detection

UAV remote sensing will be correlated with in-place sensors to obtain bridge condition assessment data without the need to place heavy instrumentation on the structure. The ability to acquire this information remotely for many bridges without the expense of a dense sensor network will provide more accurate and near real-time assessments of bridge condition. Improved assessments allow for limited resources to be better allocated in repair and maintenance efforts, thereby extending the service life and safety of bridge assets, and minimizing costs of service-life extension. There are some experiments that are done to use camera and mini-LiDAR to detect bridge conditions. This study will assess the feasibility, requirements and cost-effectiveness of using UAV and sensors to detect bridge conditions.

7. UAV for Air Quality Monitoring

Unlike the traditional ground-based measurements (e.g. vehicle-based measurements, handheld measurements), unmanned aerial vehicles (UAV) equipped with gas detection sensors provide a promising and efficient way to monitor the accumulative measurement of transportation-related air pollutants such as CO and PM. Neumann et al (2010) has verified micro-drone's capability for gas measurements in hazardous scenarios by validating the airborne system's measurements of CO2 gas concentration in a $20m^3$ test chamber. We have bought high resolution ambient CO and PM measurers, and are conducting experiment to collect 4-D (3-D spatial and temporal dimension) air quality data. The results are very promising. Preliminary study will estimate the effectiveness of using UAV to collect gas concentration data under two scenarios: point emission source (i.e. intersection) and linear emission source (i.e. an arterial road). Our own study as well as studies from the literature will provide insights regarding whether UAV could be a more efficient way to map and model transportation-related air pollution.

Deliverables:

The study will deliver detailed analysis on the user needs, UAV technology and sensor requirements and cost-effectiveness analysis for each transportation application identified with division staff from GDOT.

Significance of Research

The completed feasibility study will give GDOT an overall framework to assess the feasibility and cost-effectiveness of using UAVs to accomplish the Department's goals in a more efficient and economical way. The study will weigh the cost versus the benefits for utilizing UAVs against the traditional methods currently in use.

The user requirements for each transportation application defined in this study will also allow for more rapid deployment of test UAVs if the Department decides to explore the applications further. This study can also be a reference for other states in the nation to use for developing their own UAV applications.

Not only will this study promote advances within state and national surface transportation systems but provide a platform for research and flight testing data collection for FAA to develop accurate UAV integration policies and certification requirements. Both surface and air transportation will be positively impacted by this endeavor.

Summary of Deliverables

A summary of specific deliverables shall be listed and come from the work plan's Tasks. Dates for deliverables shall be included and related, not by calendar date, but in terms of months (half-month increments, as needed) within the total project schedule or as related to the Notice to Proceed or project completion. A Draft Final Report and a Final Report shall be included as deliverables. Any technical systems and/or interim reports or special milestone reports, as applicable, should be noted as deliverables. A project information flyer, single page and in Georgia DOT format to be provided, shall also be included as a deliverable.

Deliverables	Date
1. Report of transportation applications to be considered in the study by brainstorm with GDOT staff	2nd month
2. An Assessment Framework of UAV Applications In Transportation	4th month
3. Detailed Analysis of UAV Applications in Transportation	10th month
4. Final project report	12th month

Implementation Plan

An Implementation Plan will be included and address how the results will be implemented by GDOT. It should include the level of implementation during and after the project.

The project report will identify those transportation applications that are low-hanging fruits in UAV testing. It will provide detailed suggestion about what UAV system and sensors to purchase as well as the rough budget, and to what applications. It will also identify the UAV applications in the implementation plan for the median and long term.

Qualifications of the PI

The PI of this project, professor Peng, has extensive research experience of UAV applications in transportation since 2003. Professor Peng has finished several research projects as project director in this field both in Wisconsin, Florida and in China. His research group has already carried out many experiments, published 17 papers, applied for four patents, and developed two soft programs in this research area.

Budget Estimate

A. SALARIES:

Academic (Name):			
Zhong-Ren Peng	12.50%	12 months @ 14950/montl	$22,425
		TOTAL SALARIES	$22,425

B. OTHER PERSONNEL SERVICES (OPS):

Graduate Students (1) stipend	50%	12 months	$13,200
Fee waivers for graduate student			$11,541
		TOTAL OPS	$24,741

C. FRINGE BENEFITS:

23.2% faculty benefit rates	$5,203
4.4% Graduate Assistant benefit rate	$581
TOTAL FRINGE BENEFIT	$5,784
TOTAL SALARIES, OPS & FRINGE BENEI	$52,950

D. TOTAL PERMANENT EQUIPMENT: OCO $0

E. TOTAL OPERATING EXPENSES:

Materials & Supplies, and data	$1,200
Supplies for UAV	$2,000
Communications	$850
Travel to conferences	$1,500
Travel to GDOT and fieldwork	$1,500
EXPENSES	$7,050

F. TOTAL DIRECT COSTS: $60,000

G. TOTAL INDIRECT COSTS: 25.0% TDC $15,000

H. TOTAL BUDGET: $75,000

Budge justifications

PI, Dr. Zhong-Ren Peng 1.5 months of summer support
1 Research Assistant, 50% for 12 months
Travel: $1500 for PI and RA to go to conferences and $1500 to go to meetings at GDOT and field wc
Materials & Supplies and data: $1200
Supplies for UAV related devices: $2000
Field communications (data and voice): $850

Work Plan Schedule

Activity	Timeframe
Meeting with DGOT staff	1st month
Literature Search	1-2nd month
Draft report: Main applications of UAV for transportation	End of 2nd month
Draft report: An Assessment Framework of UAV Applications In Transportation	4th month
Draft report: Detailed Analysis of UAV Applications in Transportation	10th month
Final report	12th month

Support Required from Georgia DOT

If any assistance such as data, equipment, or personnel will be needed from the Department or other agencies, public or private, describe the specific work elements needed.

- Personnel in GDOT divisions which are the potential users of UAV will be involved in the survey and interview.
- Traffic data of the road and personal coordination for UAV experiments if experiments are to be conducted.
- Reviewing the draft and final research report.

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